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Photoperiodic response of two newly established populations of the great mormon butterfly, *Papilio memnon* L. (Lepidoptera, Papilionidae), in Shizuoka and Kanagawa Prefectures, central Japan

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Abstract The photoperiodic response was investigated in two newly established populations of *Papilio memnon* in Shizuoka and Kanagawa Prefectures, central Japan. Critical photoperiods for inducing pupal diapause were about 13 hr and 13 hr 15 min in the Shizuoka (35°02′N) and Kanagawa (35°16′N) populations, respectively, and these were not different from those of temperate populations in western Japan. Results show that the distribution of this species has been expanding from western into central Japan without any remarkable changes in such a physiological trait as the critical photoperiod for inducing pupal diapause.

Key words Pupal diapause, critical photoperiod, distribution, climatic warming, *Papilio memnon*.

Introduction

The distribution of the great mormon butterfly, *Papilio memnon* L. (Lepidoptera, Papilionidae), which is widely distributed in Southeast Asia, has been expanding into the northeastern area of western Japan (Fukuda *et al.*, 1982; Shirôzu, 1985; Yoshio, 1994, 1995; Yoshio & Ishii, 1998; Kitahara *et al.*, 2001). The northern limit, which had lain in the westernmost part of Honshu and the southern part of Shikoku in the early 1940s, advanced to the eastern coast of Kii Peninsula by the early 1990s (Fig. 1). The recent expansion of distribution is rapid so that this species was found in Saitama Prefecture in 2000 (Makibayashi, 2000) and in downtown Tokyo in 2001 (Saito, 2001) after establishing new populations on the Pacific Coast in Shizuoka and Kanagawa Prefectures, central Japan from the late 1990s to 2000 (Morishita, 2000; Kishi, 2001; Suwa, 2003).

It may be true that orange farms and citrus trees including *Citrus* spp., *Poncirus trifoliata* and *Fortunella japonica* in gardens and parks have supported the expansion of the distribution of this species by the providing larvae with a food source (Ishii, 1998; Ishii & Yoshio, 2004). However, it is not possible to explain the recent northward invasion of this species only by the extension of availability of food plants, because they have long been grown in western Japan. Yoshio and Ishii (1998, 2001) suggested that the recent climatic warming is a major factor influencing the rapid northward invasion of this species, since there was no substantial change in physiological traits such as the critical photoperiod for inducing pupal diapause, intensity of diapause and cold tolerance of diapausing pupae among three temperate populations in western Japan.

In this study, we carried out a simple experiment to investigate the critical photoperiod for inducing pupal diapause (CP) in the Shizuoka and Kanagawa populations of this species to confirm the above hypothesis.

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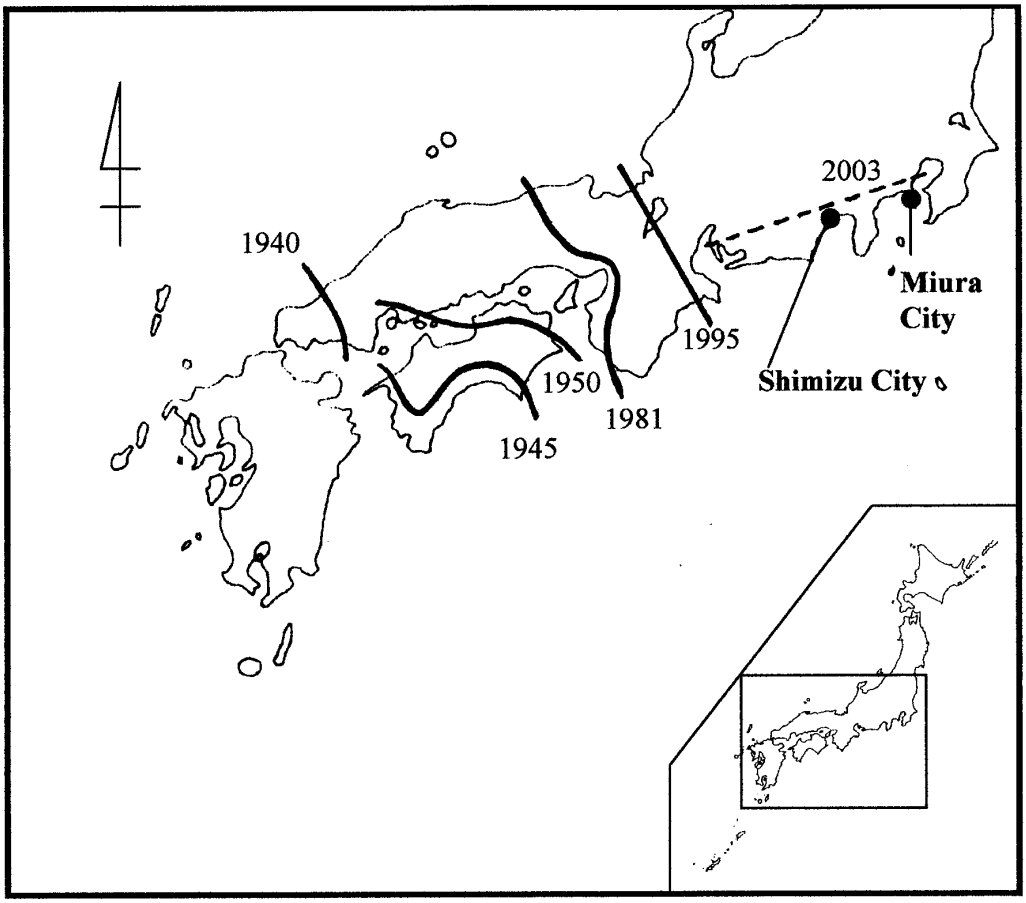

Fig.1. Changes in the northeastern boundary of distribution of *Papilio memnon* in Japan. Closed circles indicate localities where females of this species were collected for this study. The distribution boundary in 1940 was drawn from Shirôzu (1985), those in 1945, 1950 and 1981 from Fukuda *et al.* (1982), 1995 from Yoshio (1995).

Materials and methods

Eggs of *P. memnon* were obtained from a single female collected in Shimizu City (35°02′N) in Shizuoka Prefecture, Tokai district, on 17 August 2001, and one in Miura City (35°16′N) in Kanagawa Prefecture, Kanto district, on 29 August 2001, respectively. Newly hatched larvae were reared on an artificial diet (Yoshio & Ishii, 1996) under various temperature and photoperiodic conditions, 12L-12D at 18±0.5°C, 12.5L-11.5D at 17±0.5 °C, 13L-11D at 18±0.5°C, 13.5L-10.5D at 18±0.5°C and 14L-10D at 19±0.5°C. Pupae were kept under the same conditions as the larval stage until adult eclosion, and individuals whose pupal stage lasted more than 30 days were regarded as diapausing in this study. This definition is longer than that of Yoshio & Ishii (1998) by 5 days because temperature conditions were slightly lower in this experiment. Durations of larval and pupal periods were recorded.

Results and discussion

The mean larval stages were about 40 days and were not remarkably variable between photoperiodic conditions in either the Shizuoka or Kanagawa populations (Table 1). However, means under 12.5L-11.5D were slightly longer than those under other photoperiods in both populations (by Tukey test, $P<0.05$, Table 1). Lower temperatures

Table 1. Mean larval and pupal stages (mean±S. D. days) of the Shizuoka and Kanagawa populations of *P. memnon* reared under various photoperiods at 17–19°C.

Photoperiod	Temperature (°C)	Larval stage (mean±SD)		Pupal stage of non-diapausing individuals (mean±SD)	
		Shizuoka	Kanagawa	Shizuoka	Kanagawa
12L-12D	18	———	42.2±2.3 ab (24)	———	———
12.5L-11.5D	17	45.2±3.5 a (21)	43.3±3.8 a (29)	26.7±0.6 (3)	26 (1)
13L-11D	18	42.4±3.9 b (25)	42.1±2.3 ab (31)	25.7±1.3 (11)	25 (2)
13.5L-10.5D	18	40.4±2.8 b (21)	41.1±3.5 b (30)	24.8±0.9 (19)	23.4±0.8 (22)
14L-10D	19	———	40.4±3.5 ab (8)	———	23.5±0.5 (8)

Means followed by the same letter in the same column in larval stage are not significantly different by Tukey test ($P > 0.05$). Numbers in parentheses show sample size.

might extend larval development. The results show that larval development is not affected by the photoperiod and not different between the two populations.

Both populations showed a long-day response with the short day inducing pupal diapause. The mean pupal stages of non-diapausing pupae were about 25 days and not remarkably variable between photoperiods and populations (Table 1). The photoperiodic response curve showed that the CPs were about 13 hr and 13 hr 15 min in the Shizuoka and Kanagawa populations, respectively (Fig. 2). The CPs of both populations were not remarkably different from those of other temperate populations in Kagoshima City (31°36′N), Kyushu district, and Wakayama (34°11′N), and Mino (34°54′N) Cities, Kinki

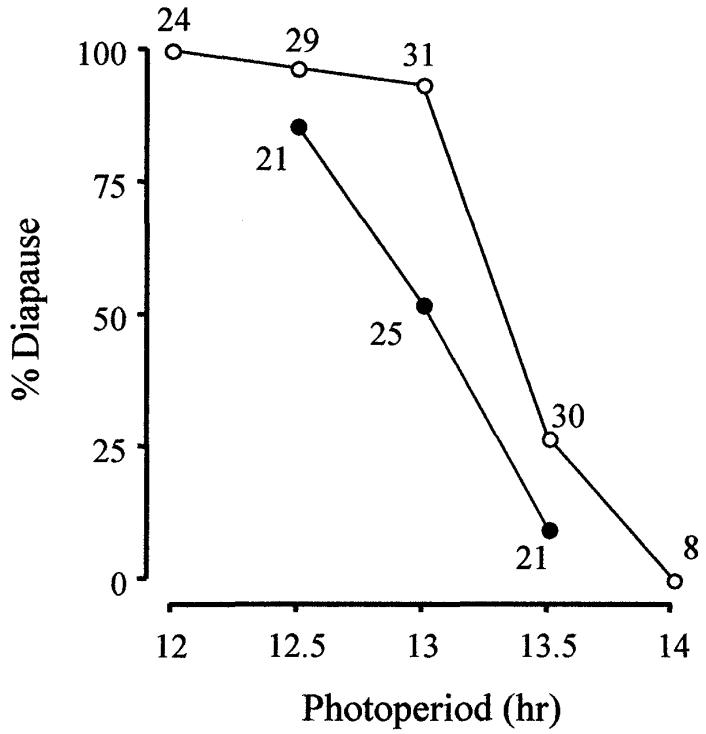

Fig.2. Incidence of pupal diapause in the Shizuoka (●) and Kanagawa (○) populations of *Papilio memnon* reared under different photoperiods at 17–19°C. Sample sizes are given in the figure.

district (Yoshio & Ishii, 1998).

It is known that insects inhabiting temperate regions show geographical variation in CP (*e. g.* Danilevsky, 1965; Tauber *et al.*, 1986; Danks, 1987), and it is roughly estimated that a difference of five degrees in latitude is reflected as about one hour in CP (Masaki & Yata, 1988). Latitudinal variations in CP between populations from the Kyushu and Kanto districts were reported in several insects such as *Pieris melete* Ménétriès (Yata *et al.*, 1979; Hashimoto, 1993), *Pieris rapae crucivora* Boisduval (Yata *et al.*, 1979; Hashimoto, 1996), and *Locusta migratoria* L. (Tanaka, 1994). In contrast, *Papilio memnon* shows no remarkable difference in CP between populations from the Kyushu and Kanto districts. The results show that the distribution of *P. memnon* has been expanding from the Kyushu district into the Kanto district without any remarkable change in CP, which supports the hypothesis that the recent climatic warming may be influencing the northward invasion of this species (Yoshio & Ishii, 1998, 2001; Kitahara *et al.*, 2001).

It is interesting that CP of the Kanagawa population of *P. memnon* was shorter than that of the Tokyo (35°41′N) population of *Papilio protenor demetrius* Cramer (13 hr 47 min, Ichinosé & Negishi, 1979). Considering that the critical photoperiod for inducing winter diapause is generally shorter at high temperatures (*e. g.* Danks, 1987), the difference between the two species may be larger than 30 minutes at the same temperature. Hence it is possible that *P. memnon* enters diapause much later than *P. protenor* in the southern Kanto district. The recent climatic warming might help *P. memnon* to establish new populations in the southern Kanto district by increasing the autumnal temperature to ensure pupation before the coming of winter cold.

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摘　　要

ナガサキアゲハの静岡および神奈川における新規個体群の光周反応 (吉尾政信・石井　実)

ナガサキアゲハ *Papilio memnon* L. は, 近年, 日本国内において分布を北方あるいは東方へ拡大している. 1940年代の北限は本州および四国の一部であったが, 1990年代前半には紀伊半島に侵入した. その後も太平洋沿いに分布を拡大し, 1990年代後半から2000年にかけて静岡県や神奈川県で定着が確認されるようになった (岸, 2001; 諏訪編著, 2003).

本種の寄主植物である柑橘類は西日本では古くから広く栽培されており, 近年における分布拡大は柑橘類の栽培地域の拡大では説明できない. Yoshio & Ishii (1998, 2001) は, 本種の西日本の3個体群間では休眠性と耐寒性は明瞭な差がないことを示し, 近年における本種の分布拡大には気候温暖化が関与していると報告している. 本研究では, この仮説を確認するために, 侵入・定着直後の静岡県 (35°02′N) と神奈川県 (35°16′N) の本種個体群について, その光周反応を調べた.

その結果, 静岡・神奈川個体群ともに長日型の光周反応を示し, 短日で蛹休眠が誘起された. 蛹休眠を誘起する臨界日長 (CP) は, 静岡個体群で約13時間, 神奈川個体群では約13時間15分であり, これらはYoshio & Ishii (1998) が報告した鹿児島 (31°36′N), 和歌山 (34°11′N), 箕面 (34°54′N) の各個体群と変わりなかった. 温帯では, 多くの昆虫で休眠性に地理的変異が存在することが知られ, 冬休眠の場合, 生息地の緯度が約5度違えば, CPには約1時間の差がみられる傾向がある (正木・矢田, 1988). しかしながら, 本種では鹿児島と神奈川個体群間でもCPに差は認められなかった. この結果はすなわち, 本種の分布拡大が気候温暖化によるとする上述の仮説を支持している.

本種の神奈川個体群のCPは, 東京産のクロアゲハのもの (23°Cで約13時間47分, Ichinosé & Negishi,

1979) よりも約30分短かった. 一般に冬休眠を誘起する臨界日長は高温では短くなることを考慮すれば, 本種は関東地方南部ではクロアゲハよりも秋遅くに休眠に入ると考えられる. 近年の気候温暖化によって秋の気温が上昇し, 冬の到来が遅くなっていることも, 本種の関東地方での定着に有利にはたらいているのかもしれない.

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